Geologic Map of the Hedgepeth Hills
7.5' Quadrangle, Maricopa County, Arizona

by

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Arizona Geological Survey
Open-File Report 98-18

November, 1998

This report was supported by the Arizona Radiation Regulatory Agency, with funds provided by the U.S. Environmental Protection Agency through the State Indoor Radon Grant Program, the U.S. Geological Survey via the STATEMAP program, and the Arizona Geological Survey.

This report is preliminary and has not been edited or reviewed for conformity with Arizona Geological Survey standards.
INTRODUCTION

The Hedgpeth Hills Quadrangle is located in the northwestern Phoenix metropolitan area, between Interstate 17 (I-17) and the Agua Fria River (Figure 1). The quadrangle is bounded by latitudes 33°37'30"N and 33°45'00"N, and longitudes 112°07'30"W and 112°15'00"W. The Hedgpeth Hills area is highly urbanized and is still undergoing rapid population growth. Thus, the knowledge of the distribution and character of bedrock and surficial deposits is important to make informed decisions concerning management of the land and its resources.

Geologic mapping of the Hedgpeth Hills Quadrangle is related to other 1:24,000 scale mapping projects in and around the Phoenix metropolitan area (Figure 1). Geologic mapping of bedrock and surficial units in the quadrangle was based upon both field observations and interpretation of aerial photographs and soil surveys. Mapping of Quaternary surficial deposits was initially done by Huckleberry, whereas final mapping and interpretation of bedrock and surficial units was completed by Leighty. A limited amount of unpublished Arizona Geological Survey mapping (by Steve Reynolds and Mike Grubensky for the Phoenix North 1:100,000 scale geologic map) augmented the new mapping of this report. Also, the mapping of Tertiary rocks by Jagiello (1987) is locally similar to that of this report. Aerial photographic coverage of the quadrangle is available from various sources (e.g., U.S.G.S., Bureau of Land Management, etc.), and includes black-and-white (1:20,000-scale, dated 1-19-70; 1:40,000 scale, dated 9-6-92), and color (1:24,000 scale, dated 10-25-77) photographs. Soil information was compiled from USDA Maricopa County soil surveys (Hartman, 1977; Camp, 1986). This project was funded by the Environmental Protection Agency through the State Indoor Radon Grant Program, the U.S. Geological Survey via the STATEMAP program, and the Arizona Geological Survey.

PREVIOUS STUDIES

Geologic investigations in the Hedgpeth Hills Quadrangle have been somewhat limited. The Proterozoic geology of the region has been summarized (Karlstrom et al., 1987; Karlstrom and Bowring, 1988, 1991; Anderson, 1989a,b; Karlstrom et al., 1990; Reynolds and DeWitt, 1991), but more detailed studies have typically concentrated in the Phoenix Mountains, New River, New River Mountains, and Bradshaw Mountains areas (Aylor, 1973; Shank, 1973; Thorpe, 1980; Thorpe and Burt, 1978, 1980; Maynard, 1986, 1989; Anderson, 1989a,b; Bryant, 1994; Jones, 1996; DeWitt, unpub. mapping; Grubensky, unpub. mapping; Reynolds, unpub. mapping). Other geologic studies have emphasized the Tertiary rocks and structures (Gomez, 1978; Gomez and Elston, 1978; Elston, 1984; Jagiello, 1987; Doorn and Pévé, 1991; Leighty et al., 1995; Leighty and Reynolds, 1996; Leighty, 1997). The uranium potential of Tertiary sedimentary deposits of the region was described by Scarborough and Wilt (1979), some of which may be potential radon hazards (Duncan and Spencer, 1993; Harris, 1997; Harris et al., 1998). Huckleberry (1995) described the Quaternary deposits of the Agua Fria River to the west. The Hedgpeth Hills area is also included in the 1:100,000 scale Phoenix North 30’ x 60’ Quadrangle (Demsey, 1988; Reynolds and Grubensky, 1993). This study is contiguous with 1:24,000 scale geologic mapping recently completed in nearby quadrangles, including Biscuit Flat (Leighty and Huckleberry, 1998b), Union Hills (Holloway and Leighty, 1998), New River SE (Leighty and Holloway, 1998), Cave Creek (Leighty et al., 1997), Wildcat Hill (Skotnicki et al., 1997), New River Mesa (Ferguson et al., 1998), and Humboldt Mountain (Gilbert et al., 1998) Quadrangles.

PHYSIOGRAPHY

Arizona can be divided into three physiographic/geologic provinces (Figure 1): the Colorado Plateau, the Transition Zone, and the Basin and Range. The Hedgpeth Hills Quadrangle lies within the Basin and Range province in central Arizona, where the terrain includes NW-trending mountain ranges separated by alluvial valleys. The area north of Phoenix includes a number fault-bounded, NE-dipping, mountain
Figure 1. Location of the Hedgpeth Hills 7.5' Quadrangle in the Phoenix region. The inset map shows the location of the study area relative to the three physiographic provinces in Arizona: the Basin and Range (BR), Transition Zone (TZ), and Colorado Plateau (CP).
ranges consisting of highly eroded rocks of Proterozoic and Cenozoic age. Although common in other parts of Arizona, Paleozoic and Mesozoic sedimentary rocks are absent in this area. The valleys are commonly filled with Cenozoic “basin-fill” sedimentary rocks and surficial deposits, with normal faults typically buried beneath the alluvium.

The Hedgpeth Hills Quadrangle contains geologic units that range in age from Early Proterozoic to Latest Cenozoic (Figure 2). Proterozoic rocks include Early Proterozoic metamorphic and plutonic rocks and Early to Middle Proterozoic granitic to dioritic rocks. Cenozoic rocks include Middle Tertiary silicic volcanic rocks, Early Miocene alkaline basalt, conglomerate, tuff, and tuffaceous sediment, Early to Middle Miocene andesite, Middle Miocene subalkaline basaltic lavas, and Plio-Pleistocene to Holocene river terraces and alluvium.

The Hedgpeth Hills Quadrangle includes small ranges and hills, piedmonts with coalescing alluvial fans, and broad alluvial plains (Figure 2). The northern half of the quadrangle includes several fault-block ranges (e.g., Deem Hills, Hedgpeth Hills, East Wing Mountain, etc.) with topographic relief locally reaching 400 to 700 feet. The southern half of the quadrangle is a predominantly low relief alluvial surface. Prominent drainages include New River and Skunk Creek. New River is the largest stream in the quadrangle, and flows south from its headwaters in the southern Transition Zone to the north. The larger Agua Fria River is located immediately to the west. Vegetation across the area is typical of the Sonoran Desert, with various desert grasses and other cacti, including saguaro.

Access for most of the Hedgpeth Hills Quadrangle is excellent (Figure 2). Numerous paved roads (e.g., Deer Valley Road, 67th Avenue, Agua Fria Expressway, etc.) and well-maintained dirt roads make much of the area highly accessible. Most of the southern half of the quadrangle is urbanized, and active building construction is spreading northward toward the Deem Hills and East Wing Mountain. Access to the Adobe Dam area, between the East and West Wing Mountains, is restricted by locked gates. Thunderbird Regional Park is located in the central part of the Hedgpeth Hills and includes an established trail system. Areas to the north of the Deem Hills, Ludden Mountain, East Wing Mountain, and West Wing Mountain are undeveloped. Access to these areas is best from the north, via high clearance two-wheel drive and four-wheel drive roads. Although the area adjacent to the Central Arizona Project (CAP) canal is restricted, the canal can be crossed at several locations (e.g., east of Pyramid Peak).

PROTERozoIC GEoLoGY

The Hedgpeth Hills Quadrangle contains several Proterozoic lithologies located in the southwestern Hedgpeth Hills area, the Pyramid Peak area, East Wing Mountain, and Sunrise Relief Hills (Figure 2). Three main units are present: 1) Early Proterozoic intermediate metavolcanic rocks, diorite, and ferruginous quartzite, 2) Early to Middle Proterozoic granodiorite, diorite, and tonalite, and 3) Early to Middle Proterozoic coarse-grained granite. Similar Proterozoic rocks are also exposed in nearby quadrangles (Anderson, 1989b; Reynolds and DeWitt, 1991; Reynolds and Grubensky, 1993; Bryant, 1994; Leighty et al., 1997; Leighty and Huckleberry, 1998; Holloway and Leighty, 1998; Leighty and Holloway, 1998). Middle Proterozoic sedimentary rocks (e.g., Apache Group), common in the Transition Zone to the northeast, are absent in the Phoenix area.

Early Proterozoic rocks

The Early Proterozoic rocks of the Hedgpeth Hills Quadrangle include metavolcanic rocks (Xva), diorite (Xd), and ferruginous quartzite (Xrq). Fine-grained (greenschist facies or lower) intermediate metavolcanic rocks (Xva) are present in the central Hedgpeth Hills and East Wing Mountain areas, along with minor amounts of more foliated pelitic rocks. The metavolcanic rocks are typically aphyric, but are locally plagioclase-phyric, with very fine-grained, chloritic groundmass. These rocks probably range
Figure 2. Generalized bedrock geology of the Hedgpeth Hills 7.5' Quadrangle with significant landmarks.
from basaltic andesite to andesite in composition, but more mafic lavas are unlikely due to the absence of olivine. In the central Hedgpeth Hills, these lavas locally contain calcareous patches, epidote alteration, and vesicle patterns that may define the margins of pillows (Reynolds and DeWitt, 1991). Protoliths of this unit likely include basaltic andesite to andesitic lavas, with lesser dacitic compositions, and minor amounts of tuff and reworked tuff. Diorite (Xd) is exposed in the southwesternmost hill in Thunderbird Park. It is not clear how this unit is related to the adjacent metavolcanic rocks. However, this unit is locally micaceous in proximity to the YXgl unit, suggesting some degree of contact metamorphism.

Fine-grained ferruginous quartzite (Xfq) and ferruginous chert (oxide-facies iron-formation) are present in the Hedgpeth Hills and East Wing Mountain, respectively. These rocks are resistant, very fine-grained, and form dark red to black lenses (typically <10 m wide). Specular hematite is common along fractures and quartz veins are abundant.

The Early Proterozoic rocks in this quadrangle are likely part of an Early Proterozoic terrane that contains rocks of similar age, metamorphic grade, and deformational fabric, largely represented by rocks of the Tonto Basin Supergroup and Diamond Rim Intrusive Suite (1740 to 1680 Ma; Anderson and Guilbert, 1979; Maynard, 1986, 1989; Reynolds et al., 1986; Anderson, 1989a,b; Conway and Silver, 1989). The metavolcanic rocks (Xva) in Thunderbird Park may specifically correlate with the mafic to intermediate metavolcanic rocks of the Union Hills Group, the oldest part of the Early Proterozoic Tonto Basin Supergroup (Anderson and Guilbert, 1979; Karlstrom et al., 1987; Anderson, 1989a,b; Conway and Silver, 1989). The Union Hills Group is composed of: 1) mafic, intermediate, and felsic volcanic rocks and related tuffs, that were deposited in proximity to submarine volcanic centers, and 2) intermediate composition volcanic and volcaniclastic rocks and sediments deposited distally from major volcanic centers (Anderson, 1989b).

**Early to Middle Proterozoic intermediate to mafic plutonic rocks**

A largely undeformed, intermediate to mafic plutonic complex, informally named the tonalite of Biscuit Flat (Reynolds and DeWitt, 1991), is exposed at East Wing Mountain, in the Sunrise Relief Hills, and locally in the Pyramid Peak area. Equigranular granodioritic to dioritic rocks (YXgd), that locally may include tonalite, are exposed in the Sunrise Relief Hills. At East Wing Mountain, the plutonic rocks include diorite, microdiorite, gabbro, and granodiorite (YXd) that intrude the metavolcanic rocks (Xva). The plutonic rocks (YXgd, YXd) appear fresh in outcrop, but are strongly altered and metamorphosed in thin section: plagioclase is extensively replaced by carbonate minerals, and epidote minerals constitute much of the groundmass (Reynolds and DeWitt, 1991). This style of alteration and metamorphism is similar to that of the Badger Spring Granodiorite (1740 ±10 Ma; Anderson et al., 1971) north of New River (DeWitt, unpub. data). These plutonic units may either be: 1) Early Proterozoic intrusions slightly younger than the metavolcanic rocks (Xva), or 2) a more mafic, comagmatic facies of the coarse-grained granite (YXg).

**Early to Middle Proterozoic granitic rocks**

The granodioritic-dioritic and andesitic rocks are both intruded by an unfoliated, coarse-grained, variably porphyritic biotite granite (YXg). This granite has been informally named granite of Pyramid Peak (Reynolds and DeWitt, 1991). Most exposures of this granite contain scattered K-feldspar phenocrysts as long as 2 cm. In the East Wing Mountains, the granite has a border phase of fine-grained, nearly aplitic biotite granite. In the Sunrise Relief Hills, coarse-grained granite locally intrudes granodioritic-dioritic rock (i.e., the tonalite of Biscuit Flat). The coarse-grained granite is likely correlative with the large granite batholith (1422-Ma, C. Isaacson, pers. comm.) exposed in the McDowell Mountains-Carefree area to the northeast, as well as other megacrystic granites (1425 to 1335 Ma) in Arizona (Silver, 1968; Livingston and Damon, 1968). These “anorogenic” granites are part of an extensive belt of granitic batholiths extending from the mid-continent region to the Mojave Desert (Anderson, 1983; Dickinson, 1989). However, it is possible that this relatively unfoliated granite is a post-tectonic Early Proterozoic granite.
In the Pyramid Peak area, areas marginal to granitic bedrock include granitic pediment or very thin mantles of alluvial deposits (typically a few meters or less thick) over pediment. These YXg(p) deposits are typically poorly indurated and are composed of grussy, sand- and silt-sized material shed from the granitic bedrock.

A relatively undeformed, leucocratic granite (YXgI) intrudes the metavolcanic rocks in the Thunderbird Park area of the southwestern Hedgpeth Hills. This rock may be a highly differentiated, pluton-marginal intrusion of either Early or Middle Proterozoic age.

CENOZOIC GEOLOGY

Cenozoic rocks exposed in the Hedgpeth Hills Quadrangle include Late Oligocene to Miocene intermediate and felsic flows and breccia, Early Miocene alkaline basalt, conglomerate, tuffaceous sediment, and felsic tuff, Middle Miocene subalkaline basaltic lavas, and Quaternary surficial deposits. Most of the Tertiary basaltic lavas, tuffs, and sedimentary rocks are correlative with either the Chalk Canyon formation or Hickey Formation.

Tertiary felsic volcanic rocks

Although voluminous ash-flow-related volcanism occurred across the Arizona Basin and Range during the Middle Tertiary, exposures of rocks representing this volcanism are relatively sparse in the northern Phoenix area. These rocks include trachyandesite remnants (17.6-Ma) in the Tempe area (i.e., Bell Butte and Tempe Butte), trachyte in the Deem Hills, and rhyolite/dacite flow and breccia at West Wing Mountain. However, a significant volume of Early Miocene trachyandesite, rhyolite, and basalt are exposed in the Hieroglyphic Mountains (Ward, 1977; Satkin, 1981; Capps et al., 1986; Kortemeier et al., 1986; Leighty, 1997). Along the Basin and Range-Transition Zone boundary to the north, silicic volcanism was also generally potassic in composition (trachytic and trachyandesitic) and localized in extent. Late Oligocene to Early Miocene (26.5 to 17.7 Ma) trachyte, trachyandesite, and andesite domes and flows are exposed in several areas between the Agua Fria and Verde Rivers, including at western New River (26.5-Ma), Gavilan Peak (22.0-Ma), New River Mesa, and Camp Creek (Gomez, 1978; Esperanza, 1984; Jagiello, 1987; Leighty, 1997). Many of these rocks are inclusion-bearing and host crustal xenoliths. These rocks typically predate most of the other Tertiary volcanic rocks in the region and represent the initial phase of Middle Tertiary volcanism.

In the central part of the Deem Hills, trachytic volcanic rocks underlie the Chalk Canyon formation tuff and conglomerate sequence and mesa-capping Hickey Formation basaltic lavas. These steeply flow-banded felsic volcanic rocks may represent a small trachyte dome or flow, and were originally termed latites by Jagiello (1987), but chemical analyses (samples #1 and #2; see map; Leighty, 1997) show that they are more silica-rich trachyte compositions (Leighty, 1997). These lavas have porphyritic to seriate porphyritic overall textures, with a phenocryst assemblage of plagioclase + hornblende + biotite. The groundmass is dominantly devitrified brown glass, with plagioclase, hornblende, biotite, and opaque oxides.

Rhyolite/dacite flows and rhyolite breccia are exposed at West Wing Mountain. The lavas are glassy, with abundant quartz, feldspar, and biotite (~1 mm) in a pinkish, fine-grained to glassy groundmass. Hornblende (1-3 mm) is present locally, suggesting a more dacitic or rhyodacitic composition. The breccia is well-exposed beneath rhyolitic flows and contains clast-supported, subrounded blocks with biotite, quartz, and plagioclase. These lavas and breccias may correlate with similar silicic volcanic units in the Hieroglyphic Mountains to the northwest (Ward, 1977; Capps et al., 1986; Kortemeier et al., 1986; Satkin, 1981; Leighty, 1997).
Tertiary intermediate volcanic rocks

Andesitic lavas are exposed in the Deem Hills, Hedgpeth Hills, Ludden Mountain, Adobe Mountain, and West Wing Mountain areas. In the central and eastern Deem Hills, this unit underlies Chalk Canyon formation conglomeratic sandstone and tuffaceous units. However, in the Hedgpeth Hills and at Ludden Mountain, this unit overlies a similar Chalk Canyon formation basalt-tuff sequence, as well as thin Middle Miocene Hickey Formation basaltic rocks. At West Wing Mountain, andesitic rocks (Ta and Tba) overlie several tuff units, but also underlie rhyolite flows and breccias (Tr, Trb). Thus, this andesitic unit likely represents distinct, Early to Middle Miocene eruptive episodes.

Andesite underlies Chalk Canyon formation conglomeratic sandstone and tuffaceous units in the central and eastern Deem Hills. These rocks were referred to by Jagiello (1987) as quartz-bearing basalts. but are actually andesites (sample #3; see map; Leighty, 1997). As described by Leighty (1997), these andesites are hiatal porphyritic with cryptocrystalline to microtrachytic groundmass textures. Phenocryst and microphenocryst assemblages include plagioclase and plagioclase + pyroxene, with sieved and corroded plagioclase (<7 mm, An35). The pyroxene (<1 mm) is dominantly equant to granular augite, with trace columnar orthopyroxene, and the subhedral olivine (1%) is totally altered and replaced. Rounded resorbed quartz inclusions (1-5%, <3 mm) have reaction coronas of clinopyroxene and minor (0-15%) glass. Sieved plagioclase phenocrysts commonly display a distinct sieved zone near the outer margin of the crystal. Groundmass minerals include plagioclase, clinopyroxene, olivine, opaque oxides, and minor glass. These rocks are generally dense, but have up to 7% irregular, rounded vesicles.

Resorbed quartz inclusions and sieved-textured plagioclase are common in these lavas. The clinopyroxene coronas surrounding rounded quartz crystals likely formed by reaction processes. These quartz inclusions with clinopyroxene reaction rims have been commonly referred to as xenocrysts, but this term implies the specific genetic connotation that the quartz was incorporated from a foreign source unrelated to the magma. However, the quartz may simply be an early-formed phenocryst or cumulate (cognate phenocryst) of the host magma. Therefore, these features are referred to here as quartz inclusions (that may or may not be related to the magma) to avoid any genetic interpretation. Sieve-textured plagioclase crystals are probably early-formed crystallization products of the host magma, because no reaction coronas are present, nor are their compositions much different from those of the host rock plagioclase crystals (Leighty, 1997). The presence of these crystals in olivine-subalkali basalts, basaltic andesites, and andesites may imply a common genesis. For further discussion, refer to Jagiello (1987) and Leighty (1997).

Chalk Canyon formation

Early Miocene basaltic rocks, felsic tuffs, and fluvial-lacustrine sediments are present across the Hedgpeth Hills Quadrangle, including the Deem Hills, Hedgpeth Hills, Ludden Mountain, and West Wing Mountain areas. These rocks are typical of the Chalk Canyon formation, a sequence of Early Miocene alkaline basalts, fluvial-lacustrine sediments, and felsic tuffs informally named by Gomez (1978) for exposures in the Transition Zone to the northeast. Lithologic sequences within the Chalk Canyon formation are distinctive and have been recognized at locations across the region (e.g., eastern Lake Pleasant, north Phoenix, New River, Black Canyon City, Cave Creek, etc.). The Chalk Canyon formation be subdivided into lower and upper members: the lower member (23 to ~17 Ma) consists mainly of interbedded alkaline basalts and crystal/lithic tuffs, whereas the upper member is dominated by fluvial-lacustrine deposits (Lindsay and Lundin, 1972; Eberly and Stanley, 1978; Gomez, 1978; Scarborough and Wilt, 1979; Jagiello, 1987; Leighty, 1997).

Basaltic rocks. In the southeastern Hedgpeth Hills, this unit includes dark purplish gray to light grayish-brown, olivine-phyric, moderately vesicular basalt, with variably calcite-filled vesicles. Small olivine phenocrysts (less than a few millimeters) are typically altered orangish-red in a very fine-grained
groundmass. Several flow units are present, commonly having scoriaceous flow tops and bottoms. Lavas in the Hedgpeth Hills are typically porphyritic, with olivine ± clinopyroxene phenocrysts in a fine-grained groundmass. Intergranular biotite is commonly present. In the central Hedgpeth Hills, these rocks are fine-grained, amygdaloidal rocks with small altered olivine microphenocrysts in a microcrystalline medium to dark purplish gray groundmass that may contain very fine-grained biotite. These rocks are similar to the rocks exposed at Ludden Mountain, where the light gray lavas are variably amygdaloidal, altered, olivine-phyric basalts.

**Tuff.** Early Miocene tuff is exposed in several isolated places across the quadrangle, including the southeastern Hedgpeth Hills, Ludden Mountain, and West Wing Mountain areas. These tuffs are correlative with the lower member of the Chalk Canyon formation. In the Hedgpeth Hills and at Ludden Mountain, these pumice- and lithic-rich tuffs are nonwelded, and are interbedded with olivine-phyric basaltic lavas. Dark, resistant, ledge-forming, vitrophyric lithic tuff is exposed in the West Wing Mountain area. This glassy, columnar-jointed, tuff has heterogeneous clast compositions that include quartz, K-feldspar, granitic detritus, and obsidian. The top surface is eroded and overlain by ~5 m of reddish sediment with basaltic and Ttv clasts. The basal portion grades (over 2 m) into a white-tan, massive to laminated, nonwelded tuff (Tt). This unit is similar to vitrophyres exposed at Apache Peak, Pyramid Peak, and Elephant Mountain in the New River SE, Daisy Mountain, and New River Mesa Quadrangles to the northeast.

**Fluvial-lacustrine deposits.** Although the fluvial-lacustrine deposits of the upper member are absent in the Hedgpeth Hills, the Deem Hills contain a tuffaceous sandstone and conglomerate sequence above the andesite and trachyte units. The conglomerate has clasts that are dominantly granitic and granitic gneiss, and grades upward into thin carbonates and calcareous sandstones. These sediments correlate with the Early to Middle Miocene upper member of the Chalk Canyon formation.

**Hickey Formation basaltic rocks**

Middle Miocene basaltic volcanism was widespread across the Basin and Range and Transition Zone, and is dominantly represented by subalkaline lavas of the Hickey Formation and correlative rocks (Anderson and Creasey, 1958; McKee and Anderson, 1971; Eberly and Stanley, 1978; Gomez, 1978; Elston, 1984; Jagiello, 1987; Leighty and Glascock, 1994; Leighty, 1997). A series of Middle Miocene Hickey Formation basaltic flows (14.8 to 13.4 Ma) are well-exposed capping the mesas along the Basin and Range/Transition Zone boundary to the north of the Hedgpeth Hills Quadrangle. These sheet lavas are exposed in the Deem and Hedgpeth Hills and may have once extended across the much of the quadrangle. In the Biscuit Flat Quadrangle to the north, these basaltic flows (15.39 ±0.4 Ma, Scarborough and Wilt, 1979) overlie Chalk Canyon formation dolomites with a slight angular unconformity. Similar intergranular plagioclase ± olivine ± clinopyroxene subalkaline basalts and basaltic andesites also cap other fault-block ranges in the north Phoenix area (e.g., Shaw Butte, Rifle Range, etc.). Intergranular vesicles and large, open vesicles (commonly in columns or trains) also make these lavas distinctive from older the Chalk Canyon formation lavas. These Hickey Formation lavas have been referred to as the New River Mesa basalt (Gomez, 1978; Jagiello, 1987), but they simply represent the local equivalent of the more regional Hickey Formation (Leighty, 1997).

**Middle and Late Tertiary extensional tectonism**

Middle to Late Tertiary extensional tectonism significantly affected the Phoenix area, forming the distinctive Basin and Range physiography. Across the region, Early Miocene extension was fundamentally different in magnitude, style, and orientation compared with the Middle to Late Miocene period of normal faulting. However, in the north Phoenix area, there are several similarities in the style and orientation of the two extensional phases.
**Middle Tertiary.** Following relative tectonic quiescence of the Early Tertiary, significant extensional tectonism occurred across the Arizona Basin and Range during the Middle Tertiary (Late Oligocene and Early Miocene), and has been referred to as the “mid-Tertiary orogeny” (Damon, 1964). The Transition Zone and Colorado Plateau did not experience significant upper crustal extensional deformation during this time, but the reversal of regional drainage and formation of the Mogollon Rim was a likely effect of middle to lower crustal deflation in response to extension in the adjacent Basin and Range (Spencer and Reynolds, 1989). Middle Tertiary tectonism was dominantly characterized by ENE-WSW-directed extension along low-angle normal faults (or detachment faults) and subsequent fault-block rotation, typically related to the development of metamorphic core complexes (Coney, 1973; Davis and Coney, 1979; Coney, 1980; Crittenden et al., 1980; Davis, 1980; Wernicke, 1981; Reynolds, 1982; Davis, 1983; Davis et al., 1983; Lister and Davis, 1983; Reynolds, 1985; Reynolds and Lister, 1987; Spencer and Reynolds, 1989). Middle Tertiary extension in Arizona was broadly related to the evolving plate-tectonic setting of the continental margin of western North America (Atwater, 1970), and more specifically to changes in plate motions and geometries compounded by overriding of the progressively thinner and hotter subducted Farallon plate (Coney and Reynolds, 1977; Coney, 1978; Damon, 1979).

In south-central Arizona, initiation of extension-related tilting occurred before or during felsic volcanism (roughly 25 to 20 Ma) and generally ended before 17-Ma, except in a NW-trending belt adjacent to the relatively unextended Transition Zone (Fitzgerald et al., 1994; Spencer et al., 1995). Movement on detachment faults related to the South Mountain-White Tank composite metamorphic core complex was responsible for relatively large amounts of Early Miocene extension in the Phoenix area (Spencer and Reynolds, 1989). In the northern Phoenix area, the South Mountain detachment fault is visible on seismic reflection profiles (Frost and Okaya, 1986) and projects in the subsurface to the northeast beneath the NW-trending, tilted fault-block ranges that represent the upper plate of the core complex (Spencer and Reynolds, 1989). This area of generally unidirectional, NE-tilting in the Basin and Range has been referred to as the Camelback tilt-block domain (Spencer and Reynolds, 1989). Several SW-dipping normal faults are responsible for the northeast tilting of the Rifle and Deadman Wash Ranges. The amount of displacement along these faults is not known, but the faults may be listric in geometry to account for fault-block rotation. The map cross sections depict several small half-graben structures formed by SW-side-down movement along one or more normal faults. These faults are covered by Late Cenozoic deposits and can only be inferred from stratigraphic relations and well-log data. However, well-log and detailed gravity data are not available for much of the area. The cross sections assume a relatively shallow depth to bedrock in this area (<1000-1500 feet) due to the lack of any pronounced gravity anomalies (Lysonski et al., 1980; Oppenheimer and Sumner, 1980, 1981).

During the Early and Middle Miocene, synextensional basaltic lavas, sedimentary rocks, and tuffs of the Chalk Canyon formation (23 to ~15 Ma) and Hickey Formation (16 to <10 Ma) were erupted/deposited across central Arizona. Hickey Formation sheet lavas may have extended across the much of the northern Phoenix area, where the youngest dated lavas are 15.4-Ma in the eastern Biscuit Flat Quadrangle. Similar lavas cap many of the other ranges in the Phoenix area. Accordingly, the NE-directed tilt-block rotation occurred sometime after 15.4-Ma (and possibly <13.4-Ma), probably with movement along large, possibly listric, SW-dipping normal faults. This extension may have been related to waning metamorphic core complex extension and/or block faulting of the Basin and Range Disturbance (Menges and Pearthree, 1989; Leighty and Reynolds, 1996). However, the post-15.4-Ma rotation of these fault-blocks is significantly younger than the inferred age of active metamorphic core-complex extension. Indeed, this rotational style of faulting may have overlapped to some degree with the beginning of high-angle normal faulting of the Basin-and-Range Disturbance (Menges and Pearthree, 1989; Leighty et al., 1996). To explain these relationships, it has been suggested that the long duration and magnitude of core-complex extension adjacent to the Transition Zone are consistent with a more passive mechanism of extension where the gravitational potential energy of the thicker Transition Zone crust caused southwest-directed collapse (Spencer et al., 1995).
Late Tertiary. The Basin-and-Range Disturbance represents a period of graben subsidence that occurred along high-angle normal faults, largely without major crustal block rotation. In the Arizona Basin and Range, it began ~15-Ma and ended ~8-Ma (Eberly and Stanley, 1978; Menges and Pearthree, 1989). Basin subsidence was probably not simultaneous, but mostly occurred before 8-Ma when differential vertical movement essentially ceased, pediments formed, and basins filled (Shafigullah et al., 1980). Newly created basins filled with undeformed fluvial and lacustrine deposits and basaltic rocks that were deposited over tilted beds deformed by earlier mid-Tertiary normal faulting. Subsidence also disrupted the Early Miocene drainage, facilitating internal drainage in many basins (Shafigullah et al., 1980). Similar elevations of pediment gravel layers suggest that basin subsidence occurred with little or no change in the absolute elevation of the surrounding ranges (Peirce, 1976; Peirce et al., 1979). From well log and geophysical data, the depth of several of the large, deep Miocene basins (e.g., the Paradise Valley basin) in the Phoenix metropolitan area exceeds 10,000 feet (Oppenheimer, 1980). Much of the Hedgpeth Hills Quadrangle is entirely covered by Quaternary surficial deposits, but existing geophysical evidence (Lysonski et al., 1980; Oppenheimer and Sumner, 1980, 1981) does not support the presence of large, high-angle normal faults nor deep structural basins. However, the Like Basin (>10,000 feet deep) is present to the west and southwest of the quadrangle.

QUATERNARY GEOLOGY

Quaternary surficial deposits cover much of the Phoenix area, and include Pleistocene to Holocene alluvial fan, channel, and terrace units (Demsey, 1988; Pearthree et al., 1997). Piedmont deposits were shed onto the broad plains that slope gently down from mountain ranges toward basin floors. These deposits are generally poorly sorted, containing particles that range in size from silt or clay to cobbles or boulders. Piedmont deposits grade or interfinger downslope into finer-grained deposits. The older alluvial deposits are predominantly exposed marginal to the various bedrock ranges in the area. These sediments are typically extensively eroded, leaving rounded ridges between modern channels. Late Pleistocene and Holocene alluvium is exposed either as fairly narrow bands along washes or as broad thin, basin-covering veneers. Riverine sediments include active channels and one or more terrace levels that record former, higher positions of the stream channels. These deposits are differentiated from piedmont deposits by their diverse lithologic composition, clast rounding, and landform morphology. In the Phoenix area, these deposits are mainly related to the development of the Salt River, Gila, Agua Fria, New River, and Cave Creek drainage systems. River terraces are also commonly elongate landforms that mimic the general trend of the modern rivers.

Quaternary deposits

Quaternary surficial deposits cover much of the Hedgpeth Hills Quadrangle. These deposits include alluvial fan, channel, and terrace units that range in age from Middle Pleistocene to Holocene. Similar units in the Phoenix region are described Demsey (1988) and Pearthree et al. (1997). Piedmont deposits are shed onto the broad plains that slope gently down from mountain ranges toward basin floors and include Middle Pleistocene to Holocene alluvium (Qy, Qy, Ql, Qml, and Qm). These deposits are generally poorly sorted, containing particles that range in size from silt or clay to cobbles or boulders. Piedmont deposits grade or interfinger downslope into finer-grained deposits. The older alluvial deposits are estimated to be of Middle Pleistocene age (Qm) and are predominantly exposed marginal to the various bedrock ranges in the area. These sediments are typically extensively eroded, leaving rounded ridges between modern channels. Most Late Pleistocene and Holocene alluvium (Ql and Qy) is restricted to fairly narrow bands along washes. Riverine sediments include active channels and one or more terrace levels that record former, higher positions of the stream channels. These deposits are differentiated from piedmont deposits by their diverse lithologic composition, clast rounding, and landform morphology. In the Hedgpeth Hills Quadrangle, these deposits are mainly related to the development of the New River and Skunk Creek drainages. The New River drains a large, geologically diverse area, so its sediments has
likely been transported a considerable distance before being deposited in this area. Thus, clasts are more rounded than those in piedmont areas. River terraces are also commonly elongate landforms that mimic the general trend of the modern rivers.

**MINING**

A small number of shafts, adits, and prospects are present in the Proterozoic rocks of Sunrise Relief Mountain and East Wing Mountain. These workings are surrounded by small amounts of tailings that contain variable amounts of quartz, hematite, malachite, and chrysocolla. The coarse-grained granite exposed in the Pyramid Peak area may have once been mined for use as decorative yard rock.

**GEOLOGIC HAZARDS**

Flooding is probably the most serious geologic hazard of the Hedgpeth Hills Quadrangle. Potential flood hazards consist of inundation and erosion along the New River, Skunk Creek, and their larger tributaries, and flash-flooding associated with the smaller tributary streams that flow across the piedmonts of the area. The New River is a moderately large drainage that heads in the Transition Zone northeast of the Hedgpeth Hills Quadrangle. Thus, the New River is capable of generating large floods, and its principal tributaries can generate smaller, but still significant, 100-year floods. These floods involve deep, high-velocity flow in the channels, inundation of overbank areas, and may cause substantial bank erosion along the channels. Areas mapped as Qycr are likely to be affected by deep, high velocity flow during floods. Areas near the large streams covered by older deposits (Ql, Qlr, and older) generally are not subject to inundation, but they may be affected by lateral stream erosion. Tributary channels (Qy) are also likely to be subject to shallower inundation, and local bank erosion. The Central Arizona Project (CAP) canal and the Adobe Dam help to mitigate the damaging effects of tributary flooding.

Flood hazards associated with smaller tributaries may be subdivided into: 1) localized flooding along well-defined drainages, where there is substantial topographic confinement of the wash, and 2) widespread inundation in areas of minimal topographic confinement (i.e., active alluvial fans). Delineation of flood-prone areas along well-defined drainages is fairly straightforward, and these hazards may be mitigated by avoiding building in or immediately adjacent to washes. Thus, the extent of young deposits (Qy) on piedmonts is an accurate indicator of areas that have been flooded in the past few thousand years. These are areas that are most likely to flood in the future.

Several types of soil/substrate problems may be encountered in the Hedgpeth Hills Quadrangle. Soil compaction or expansion upon wetting or loading may be an important geologic hazard in limited portions of the quadrangle. Soil instability has caused extensive damage to buildings in Arizona (Christenson et al., 1978; Pêwé and Kenny, 1989). Changes in soil volume beneath structures may cause damage ranging from nuisance cracks to serious structural damage. Deposits that are susceptible to compaction are typically relatively fine-grained, young sediments. Local deposits that are candidates for compaction are the fine-grained terrace deposits (i.e., Qy, Qyr, and Ql). Clay-rich soils associated with the well-preserved Early and Middle Pleistocene alluvial fans (Qo and Qm) may have some potential for shrinking and swelling during dry and wet periods, respectively. However, clay-rich horizons associated with these surfaces are generally less than 1 m thick, so their shrink-swell potential is probably limited. The presence of cemented caliche (petrocalcic soil horizons) or shallow bedrock may impact construction excavation and leaching potential. Calcium carbonate accumulates in soils in this desert environment over thousands to hundreds of thousands of years. Typically, the soils associated with Middle Pleistocene alluvium (Qm) in this area have significant accumulations of calcium carbonate, but strongly cemented carbonate soil horizons are not common. Petrocalcic horizons are found in some middle Pleistocene alluvium (Qm) and thin hillslope deposits (Qc). Progressively less carbonate accumulation is associated with increasingly younger surfaces, so Ql and younger deposits have weakly developed carbonate horizons.
Radon, a colorless, odorless, radioactive gas, can pose potential health problem in certain circumstances. Radon can escape from the ground into overlying homes and other buildings, and result in elevated radiation exposure, and associated risk of cancer, to human lungs. Radon is a decay product of uranium, so areas with higher uranium concentrations present greater risk of elevated indoor radon levels (Peake and Schumann, 1991; Spencer, 1992). Uranium is present in all geologic materials, generally in concentrations of 1 to 10 ppm. Levels greater than 6 ppm U can be considered slightly anomalous. The alluvial basin cover in the region is not a significant radon hazard, but certain types of bedrock can have highly variable concentrations of uranium. In the Phoenix area, lithologies that have demonstrated elevated uranium levels, thus posing a potential radon hazard, include certain Proterozoic granitic rocks and Middle Tertiary sedimentary rocks (marl).

Since much of the Hedgpeth Hills Quadrangle is covered by Quaternary deposits, radon is probably not a significant hazard for much of the area. However, coarse-grained granite (YXg) underlies much of the Pyramid Peak area, and generally forms gentle slopes and low hills that are not an impediment to construction of new homes or other buildings. Uranium levels in this granite (6 ppm), measured in situ with a gamma-ray spectrometer, are considered moderate to marginally high (Harris et al., 1998). High variability of uranium levels observed in similar granitic rocks in the Cave Creek-Carefree area is possibly due to different amounts of leaching of uranium from weathered granite at or near the surface. The occurrence of local elevated uranium concentrations, plus the generally permeable character of weathered granite which allows radon to leak out of the ground (Peake and Schumann, 1991), indicate that elevated radon levels in homes built on this granite are probably more likely than on most other geologic materials in the Biscuit Flat area. The thin, calcareous sedimentary rocks (Tsl) of the Chalk Canyon formation in the Deem Hills contains anomalous uranium levels that could be a significant radon hazard (Scarborough and Wilt, 1979). Similar lakebed sediments with high radon potential are exposed in the New River, Cave Creek, and Carefree areas (Harris, 1997). This unit has limited exposure in the quadrangle, but its extent in the subsurface is unknown.
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UNIT DESCRIPTIONS

Quaternary piedmont deposits

Qc  Colluvium (<750 Ka) - Unconsolidated to moderately consolidated colluvium on gently sloping hillsides. These deposits are typically weakly bedded, subangular to angular, poorly sorted sand and gravel. Adjacent and underlying bedrock lithologies dominate the clast compositions. These hillslope deposits probably range in age from Holocene to Middle Pleistocene.

Qct  Colluvium and talus, undivided (<750 Ka) - Unconsolidated to moderately consolidated colluvium and talus deposits on steeper hillslopes. These deposits are typically include subangular to angular, poorly sorted, sand- to boulder-sized clasts. Adjacent and underlying bedrock lithologies dominate the clast compositions. These hillslope deposits probably range in age from Holocene to Middle Pleistocene.

Qy  Holocene alluvium (<10 ka) - Holocene alluvial deposits consist primarily of small active channels, and low terraces. This unit is characterized by unconsolidated, stratified, poorly to moderately sorted sand, gravel, cobble, and boulder deposits confined to the modern tributary drainages of the New River and Skunk Creek (e.g., in the Little Deer Valley and Biscuit Flat areas). Alluvial surfaces exhibit bar-and-swale topography, with the ridges typically being slightly more vegetated. Frequently mantled by sandy loam sediment. Qy surfaces have minimal or no rock varnish or desert pavement development. Late Holocene soils are minimally developed, but Middle and Early Holocene typically contain cambic horizons, weak calcic horizons (Stage I), and are noticeably reddened. Surface colors are light brown to yellowish brown, with a slight reddening with depth due to oxidation. Some of the older Qy soils may contain weakly developed argillic horizons. Qy soils are classified as Torrifluvents, Torriorthents, Camborthids, and Calciorthids. Because surface soils are not indurated with clay or calcium carbonate, Qy surfaces have relatively high permeability and porosity. All areas mapped as Qy may be subject to inundation during large floods.

QI  Late Pleistocene alluvium (10 to 250 ka) - Late Pleistocene alluvial fan surfaces and terraces consisting of moderately sorted, clast-supported sandstone and conglomerate with abundant granitic or metamorphic gravel clasts in a tan to brown sandy to silty matrix. QI surfaces are moderately incised by stream channels, but still contain constructional, relatively flat, interfluvial surfaces. Subdued bar and swale topography is common. Desert pavement and rock varnish development ranges from nonexistent to moderate. Surface colors are slightly more red (light brown to reddish yellow) than Qy surfaces. QI soils are also more strongly developed than Qy soils. QI soils commonly contain tan to red-brown argillic horizons that are weakly to moderately strongly developed. These soils typically have Stage II-III calcium carbonate development. QI soils are classified as Haplargids, Camborthids, and Calciorthids. The relatively low infiltration rates of these surfaces favor plants that draw moisture from near the surface. QI surfaces are generally not prone to flooding, except immediately adjacent to active washes.

Qm  Middle Pleistocene alluvium (250 to 750 ka) - Dissected Middle Pleistocene alluvial fan and terrace deposits that include sandy to loamy, tan sandstones and minor conglomerates with sand- to boulder-sized clasts. Qm surfaces have typically been eroded into shallow valleys and low ridges. Original depositional surfaces may be preserved along ridge crests. Desert pavement and rock varnish development is moderate to strong on stable surfaces, but variable to weak on surfaces that have been significantly eroded. Locally, Qm soils are moderately to strongly developed, with surfaces ranging in color from strong brown to reddish brown. These soils typically contain reddened argillic horizons that are moderately to strongly enriched in pedogenic clay. Calcite horizon development is typically fairly strong (Stage II-IV), but Qm soils generally do not have cemented petrocalcic horizons (caliche). These soils are classified as Calciorthids and Haplargids. Qm surfaces are not prone to flooding, except near active washes.

Qml  Middle to Late Pleistocene alluvium (10 to 750 ka) – Undivided Middle to Late Pleistocene alluvial fan and terrace deposits that cover broad areas of the southern part of the quadrangle.

Quaternary river deposits

Qycr  Active channel deposits (<1 ka) - Deposits in the active channels of the New River, Skunk Creek, and Scatter Wash. Predominantly sand and silt, especially in areas subject to overbank flooding, with clasts
ranging in size from pebbles to boulders. Clasts are subrounded to well-rounded and lithologies vary substantially. Distributary and anastomosing channel patterns are common. Most of the channel surfaces are modern in age, but vegetated bars may be several hundred years old. Alluvium in these deposits is typically well-stratified and lack any appreciable soil development. Qycr soils are typically classified as Torrifluvents or Torriorthents. Qycr surfaces are prone to flooding.

**Qyr** Holocene river terrace deposits (0 to 10 ka) – Low terrace deposits composed of unconsolidated, moderately to poorly sorted, subrounded to rounded sand- and gravel-sized clasts in a sandy to silty matrix. Typically concentrated along the New River and Skunk Creek. Landforms typically are low terraces, but minor channels are common locally. Primary fluvial bedforms (gravel bars, fine-grained swales) near the surface are absent or weakly expressed due to bioturbation. These deposits have weakly developed soils that are light brown to yellowish brown on the surface, with a slight reddening with depth. There is typically organic accumulation in the uppermost soil horizons, with slightly oxidized horizons at deeper levels. Minimal or no rock varnish or desert pavement development. Weak calcic horizons (≤Stage I) are present in Middle and Early Holocene soils. Qyr terrace soils are Torrifluvents and Camborthids. Portions of Qyr surfaces have been inundated during historical floods, and lateral bank erosion is also a hazard.

**Qlr** Late Pleistocene river terrace deposits (10 to 250 ka) - Intermediate, moderately old terrace deposits. Unconsolidated, moderately to poorly sorted, subrounded to rounded sand- and gravel-sized clasts in a sandy to silty matrix. Soils have moderate clay accumulation and carbonate development (Stage II), but no cementation. Desert pavement and rock varnish is nonexistent to moderately developed. These surfaces are not prone to flooding, but lateral bank erosion may occur where proximal to active channels.

**Qmr** Middle Pleistocene river terrace deposits (400 to 750 ka) - Terrace deposits exposed in the southeastern part of the quadrangle, although much of the area mapped as Qm may also be interpreted as Qmr. Alluvium is composed of unconsolidated sand, gravel, and cobble channel deposits with interbedded fine-grained overbank sediments. Some of the eroded Qmr landforms consist of low, rounded ridges and moderately incised stream channels. Desert pavement and rock varnish development is weak to moderate. Soils on Qmr terrace surfaces are strong brown to reddish brown and are strongly developed where they have not been highly eroded. Clay accumulation is variable, but well-preserved soils have strong, red argillie horizons with loam and clay loam textures. Well-developed calcic or petrocalcic horizons are also common (Stage III-V). Qmr terrace soils are classified as Calciortids, Paleorthids, and Paleargids.

**Qor** Early Pleistocene river terrace deposits (750 ka to 1.6, Ma) - Early Pleistocene terrace deposits of the Agua Fria River exposed in the northwestern part of the quadrangle. These terrace deposits represent the highest and oldest terrace of the Agua Fria River, and may be some of the oldest landforms in the northern Phoenix area. Deposits are weakly consolidated, moderately to poorly sorted, subrounded to rounded sand- to boulder-sized clasts in a sandy to silty matrix. Qor deposits do not contain a well-developed desert pavement, nor do they contain a very thick argillie horizon. Soil development is weak because the original depositional surface has been removed by erosion. However, a petrocalcic-petroduric horizon is commonly exposed, with broken pieces commonly scattered across the surface. There is little infiltration into these indurated soils. Qor terrace soil is mostly degraded, with a Stage V+ petrocalcic horizon that extends over 4 m in depth.

**Tertiary volcanic and sedimentary rocks**

**Tr** Rhyolite (Middle Miocene) - Flow-banded rhyolite/dacite exposed at West Wing Mountain. Glassy with abundant quartz, feldspar, and biotite (~1 mm) in a pinkish, fine-grained to glassy groundmass. Hornblende (1-3 mm) is present locally, suggesting a more dacitic or rhyodacitic composition. Overlies a related rhyolitic breccia/tuff unit (Trb). Typically desert-varnished, with grayish light brown weathered surfaces.

**Trb** Rhyolite breccia/tuff (Middle Miocene) - Creamy tan rhyolite breccia and tuff. The breccia is well-exposed beneath rhyolitic flows at West Wing Mountain, whereas more tuffaceous rocks are exposed northwest of Keefer Hill. Overlies the basalt to andesite (Tba) unit at West Wing Mountain. Clast-supported, subrounded blocks contain biotite, quartz, and plagioclase.
Tbm  
**Basalt (Middle Miocene)** - Basaltic lava flows, correlative with the Middle and Late Miocene Hickey Formation. A thin sequence of olivine-subalkali basalts caps the Deem Hills (sample #4; see map; Leighty, 1997), but are also interbedded with Ta and Tbl in the Hedgpeth Hills. These lavas are commonly different in outcrop color (dark grayish brown) than the underlying basaltic flows (dark gray to bluish gray). As described by Leighty (1997), these basalts are largely holocrystalline to hypocrystalline (0-3% glass) with intergranular to porphyritic overall textures. Phenocryst assemblages (<15% phenocrysts) include olivine, olivine + plagioclase, and olivine + clinopyroxene + plagioclase. Subhedral olivine (7-10%; <2 mm) is relatively Fe-rich (Fs0-Fe3.5) and is typically altered (Leighty, 1997). Euhedral to subhedral labradorite forms laths (<4 mm), with pyroxene (augite and pigeonite) typically being intergranular (Leighty, 1997). Microphenocrysts of the major mineral phases are ubiquitous. The groundmass is intergranular to interstitial, consisting of plagioclase (60%), clinopyroxene (25%), opaque oxides (3-5%), trace olivine, and minor (0-3%) dark brown interstitial glass (Leighty, 1997). Sieved plagioclase is common as phenocrysts (<2 mm) and microphenocrysts, and some have reaction rims. Polycrystalline plagioclase with interlocking texture is a rare inclusion, and both plagioclase and olivine glomerocrysts are observed in the porphyritic lavas (Leighty, 1997). Columnar jointing and zones of vesicles are common in outcrop. Open vesicles (3-7%) vary from large and rounded to irregular and intergranular. Typically highly desert varnished. In the Hedgpeth Hills, this dark gray to light grayish brown unit is porphyritic to intergranular, with olivine phenocrysts (<5 mm) in a fine-grained, plagioclase-rich, dark gray to medium greenish gray groundmass. Large open vesicles (mm’s to several cm’s) are common. Similar olivine + plagioclase rocks are also exposed at the southern part of Pilcher Hill. These cliff-forming basaltic lavas unconformably overlie the older basalt-tuff sequence, and have also been referred to as the New River Mesa Basalt (Gomez, 1978; Jagiello, 1987). These Hickey Formation rocks are petrographically and geochemically comparable to rocks from other nearby areas (e.g., Shaw Butte, Carefree Highway Range, eastern Lake Pleasant, etc.). In the Biscuit Flat Quadrangle to the north, a correlatable Hickey Formation flow is dated at 15.39 ± 0.4 (Scarborough and Wilt, 1979).

Tba  
**Basalt to basaltic andesite (Early to Middle Miocene)** - Basaltic to basaltic andesite lava flows. Several flows are present in the western Deem Hills, where the uppermost flows are brownish, underlain by a thicker gray sequence, with brownish lavas at the bottom. These platy lavas contain small olivine and plagioclase phenocrysts in a fine-grained, grayish purple groundmass. Olivine is mildly altered dusky brick red to olive drab. Fine-grained pyroxene is also present. These rocks have large open vesicles (<1 mm to 2 cm). At West Wing Mountain, this unit is light to medium gray, with light streaks. It is aphyric, with small (<1 mm) glassy plagioclase and highly altered olivine.

Ta  
**Andesite (Early to Middle Miocene)** - Resistant, light-gray to grayish-brown andesitic flows that typically overlie Hickey Formation basaltic rocks (e.g., Ludden Mountain, Hedgpeth Hills), but underlie Hickey Formation lavas in the Deem Hills. Thus, this unit not only erupted before Hickey Formation volcanism, but may have also erupted during and /or after Hickey Formation volcanism. These porphyritic lavas include distinctive glassy plagioclase phenocrysts and resorbed quartz inclusions rimmed by clinopyroxene (Leighty, 1997). In the central and eastern Deem Hills, this unit is a hawaiitic porphyritic plagioclase + clinopyroxene andesite, with a microcrystalline to interstitial groundmass (sample #3; see map; Leighty, 1997). Sieved plagioclase and quartz inclusions with clinopyroxene reaction rims are abundant. In the southeastern Hedgpeth Hills, this dark gray to medium dark gray unit has large glassy to white to pinkish plagioclase and rounded quartz inclusions in a fine-grained, medium dark greenish gray groundmass. Vesicles are intergranular. Thin, poorly exposed sediment is locally present between Ta and Tbl. This unit also caps Ludden Mountain, where it is a light purplish gray andesite, with glassy plagioclase (>1.5 cm), quartz, and sparse, fine-grained, altered olivine in a light purplish gray groundmass. No biotite or hornblende was observed. This plagioclase-phyric andesite weathers to a pinkish-brown or light brown, light purplish gray on fresh surface. Commonly desert-varnished. This unit is also present west of the New River in the West Wing Mountain area. At Adobe Mountain, this unit is dark brownish gray, with glassy plagioclase, resorbed quartz, small olivine phenocrysts, and trace biotite.

Tts  
**Interbedded tuff and sedimentary rocks (Early to Middle Miocene)** - White tuff, reworked tuff, tuffaceous sediment, sandstone, and marl. Unconformably overlain by Middle Miocene Hickey Formation basaltic lavas. Exposures are restricted to the Deem Hills. Likely correlatable with the upper member of the Chalk Canyon formation.

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Tsl Conglomeratic sandstone (Early to Middle Miocene) - Poorly exposed, slope-forming conglomerate and sandstone. Grades upward into thin carbonates and calcareous sandstone. Includes subangular clasts of Proterozoic granite. Exposed below the tuff and carbonate units in the Deem Hills. Equivalent to the upper member of the Chalk Canyon formation.

Ttv Vitrophyric tuff (Early to Middle Miocene) - Resistant, ledge-forming, black to red to reddish brown vitrophyric lithic tuff. Clast compositions are heterogeneous and include quartz, K-feldspar, with some granitic clasts, and obsidian. Chonchoidal fracture, glassy, and fresh. Crude columnar jointing. Eroded top surface is overlain by ~5 m of reddish sediment with basaltic and Ttv clasts. Basal portion grades (over 2 m) into a white-tan, massive to laminated, nonwelded tuff. Exposed in the West Wing Mountain area, where it overlies white nonwelded tuff, and is overlain by andesite. Similar vitrophyre is exposed at Apache Peak, Pyramid Peak, and Elephant Mountain in the New River SE, Daisy Mountain, and New River Mesa Quadrangles. Equivalent to the lower member of the Chalk Canyon formation.

Tt Tuff (Early to Middle Miocene) - Light gray to white tuff and reworked pumice-rich, vitric, and lithic tuff. This unit is dominantly nonwelded. Locally interbedded with tuffaceous sediments. This unit typically crumbles easily and forms slopes, but is locally well indurated. Tuffs are commonly interbedded with olivine-phyric basaltic lavas. In the southeastern Hedgpeth Hills, the tuff that underlies Ta, Tbm, and Tbl is grayish white, massive, pumice-rich, fine-grained (up to ~1mm) and granular, with minor small dark lithic fragments. Pumice fragments are subangular to subrounded. Coarse-grained pumice beds are common. At Ludden Mountain, the tuff contains mostly basaltic clasts, but also includes reddish plagioclace-phyric rock (some having white laminations), granitic detritus, and minor jasperoid fragments. This unit is also exposed in the West Wing Mountain area, where it underlies the vitrophyric tuff. Correlative with the lower member of the Chalk Canyon formation.

Tb Basaltic rocks, undivided (Early to Middle Miocene) - Basaltic lavas correlative with either the Early Miocene Chalk Canyon formation or the Middle to Late Miocene Hickey Formation. Commonly exposed in isolated outcrops (e.g., near Middle Mountain) or between tuff and Hickey Formation basalt and/or andesite (e.g., Ludden Mountain). These lavas are typically olivine-phyric and lack the distinctive intergranular texture of the Hickey Formation lavas. At Ludden Mountain, these medium gray to dark gray, subporphyritic olivine + plagioclase lavas overlie the lower basalt-tuff sequence (lower member of the Chalk Canyon formation). Olivine is altered reddish brown (<3-4 mm).

Tbl Basalt (Late Oligocene to Early Miocene) - Basaltic lavas correlative with the lower member of the Chalk Canyon formation (23 to ~17 Ma), a sequence of Early Miocene alkaline basalts, fluviol-lacustrine sediments, and felsic tuffs (Gomez, 1978; Jagiello, 1987; Leighty, 1997). These lavas are typically porphyritic, with olivine ± clinopyroxene phenocrysts in a fine-grained groundmass. Intergranular biotite is commonly present. Lower flows are typically altered and amygdaloidal. These basaltic lavas are probably alkaline to transitional in composition. In the central Hedgpeth Hills, these rocks are fine-grained, amygdaloidal rocks with small altered olivine microphenocrysts in a microcrystalline medium to dark purplish gray groundmass that may contain very fine-grained biotite. These rocks are similar to the rocks exposed at Ludden Mountain. In the southeastern Hedgpeth Hills, this unit includes dark purplish gray to light grayish-brown, olivine-phyric, moderately vesicular basalt, with variably calcite-filled vesicles. Small olivine phenocrysts (less than a few millimeters) are typically altered orangish-red in a very fine-grained groundmass. Several flow units are present, commonly having scoriaceous flow tops and bottoms. At Ludden Mountain, these light gray lavas are variably amygdaloidal, altered, olivine-phyric basalt. Olivine is totally oxidized dark reddish brown.

Tv1 Trachyte (Late Oligocene to Early Miocene) - Flow-banded trachyte (samples #1 and #2; see map; Leighty, 1997) exposed in the central portion of the Deem Hills. Underlies the Chalk Canyon formation basalt-tuff sequence, andesite, and Hickey Formation lavas. As described by Leighty (1997), these rocks have porphyritic to seriate porphyritic overall textures, and the dominant phenocryst assemblage is plagioclase + hornblende + biotite ± K-feldspar. Subhedral plagioclase (10-30%, <2.5 mm) is sodic (An20), but is more abundant than K-feldspar, and is typically zoned and sieve-textured. Euhedral to subhedral hornblende (<5%, <3 mm) and biotite (5%, 1.5 mm) are heavily altered to opaque oxides, with the hornblende phenocrysts commonly being concentrically zoned. The groundmass is dominantly devitrified brown glass, with microcrystalline plagioclase, hornblende, biotite, and opaque oxides.
**Proterozoic rocks**

**YXg(p) Granitic pediment deposits (Early to Middle Proterozoic)** - A layer of grus of variable thickness that mantles much of the low-relief pediment surface formed on granitic bedrock (YXg). These deposits are formed by the in situ weathering of the granite, and result in a subdued, rounded, and moderately dissected surface. Exposed in the Pyramid Peak area in the south-central part of the quadrangle.

**YXg Granite (Early to Middle Proterozoic)** - Coarse-grained, relatively unfoliated, porphyritic biotite granite. Includes light gray to light pink microcline (0.5-2 cm), clear gray quartz (2-8 mm), light gray to white plagioclase (2-6 mm), and subhedral black biotite (2-4 mm). Informally named granite of Pyramid Peak for exposures in the north central part of the quadrangle (Reynolds and DeWitt, 1991). Possibly correlative with the large granite batholith exposed north of the McDowell Mountains to the east. In the East Wing Mountains, the granite has a border phase of fine-grained, nearly aplite biotite granite with only 1 percent scattered, discrete flakes of biotite. In the Sunrise Relief Hills, this granite intrudes the tonalite of Biscuit Flat (YXd).

**YXgd Granodiorite, diorite, and tonalite (Early to Middle Proterozoic)** - Weakly foliated to massive, biotite + hornblende granodiorite, diorite, and tonalite phases exposed at Sunrise Relief Mountain. Typically desert-varnished. Diabase and Xva enclaves are common. The granodiorite or tonalite phases are medium-grained (< a few millimeters) containing ~20% mafics, with quartz, plagioclase, and minor K-feldspar. These rocks are part of an intermediate plutonic complex, informally referred to as the tonalite of Biscuit Flat (Reynolds and DeWitt, 1991). This unit includes minor exposures of gneissic, biotite-rich diorite (YXgl). This largely undeformed plutonic complex is intruded by the coarse-grained granite.

**YXd Diorite (Early to Middle Proterozoic)** - Largely unfoliated diorite and microdiorite phases exposed in the Pyramid Peak and East Wing Mountain areas. Together with the plutonic rocks at Sunrise Relief Mountain, these rocks comprise an intermediate plutonic complex, informally referred to as the tonalite of Biscuit Flat (Reynolds and DeWitt, 1991). This unit is intruded by the coarse-grained granite.

**YXgl Leucocratic granite (Early to Middle Proterozoic)** - Leucocratic, fine-grained granite with very little mafic material. Quartz, K-feldspar, and plagioclase grains up to a few millimeters in size. Exposed in the southwesternmost part of the Hedgpeth Hills.

**Xva Andesitic metavolcanic rocks (Early Proterozoic)** - Dark greenish gray, fine-grained, aphyric to plagioclase-phryic meta-andesitic rocks and amphibolite, with minor amounts of more foliated pelitic rock. Plagioclase phenocrysts are locally present in a very fine-grained, chloritic groundmass. Locally micaceous, especially near the YXgl unit. Abundant epidote veins (~15 cm thick). Weathers tan to green where not desert-varnished. Although most rocks display only metamorphic textures, meta-andesite in Hedgpeth Hills contains calcareous and epidote alteration that defines the margins of pillows (Reynolds and DeWitt, 1991). Some variations in vesicles also imply the presence of pillow lavas. These rocks may be correlated with the Union Hills Group of Anderson (1989a). Exposed in the southeastern East Wing Mountain area and in the southwestern Hedgpeth Hills, where it is associated with diorite (Xd). Protoliths may have been basaltic, dacitic, or andesitic lavas, with lesser amounts of tuff and reworked tuff.

**Xd Diorite (Early Proterozoic)** - Medium-grained diorite exposed in the southwestern Hedgpeth Hills, where it is associated with meta-andesite (Xva). Weathers gray to brown.

**Xfq Ferruginous quartzite (Early Proterozoic)** - Very fine-grained ferruginous quartzite and oxide-facies iron-formation. Resistant, brick red to purple to black lenses (typically <10 m wide). Specular hematite is commonly disseminated along fractures. Quartz veins are abundant. Exposed in the SW Hedgpeth Hills.

**d Disturbed area** - Areas of significant recent surficial disruption due to various human activities. Includes the Central Arizona Project canal, dams, etc.